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Powerfiber for Flexible Fabric and Rigid Composite Applications

By Martin H. Benson and Bernd J. Neudecker

Introduction

ITN Energy Systems, Inc. (ITN), of Littleton, Colorado, has developed a power integrated fiber based material system for a variety of single fiber, flexible laminate and textile, and rigid composite applications, or combinations thereof. These materials, called "PowerFibers", are the product resulting from the merging of solid-state, thin-film, lithium-based batteries onto fibrous substrates.

Characteristic of solid-state, thin-film, lithium-based batteries are their inherent long lifetimes of up to 90,000 charge—discharge cycles at 100% depth-of-discharge. As a result, this battery technology with fiber reinforcement offers great promise in single fiber and multi-fiber composite material applications where both long battery and host device life is required.

Individual PowerFibers can be incorporated into "PowerComposites". PowerComposites are multifunctional material systems including, for example, flexible woven or laminated composite articles for applications in wearable electronics, lightweight power integrated fabrics, and other flexible structures. Other PowerComposite applications include PowerFiber incorporation as power integrated structural reinforcement within, for example, rigid polymer matrix composites materials.

ITN has developed a strong intellectual property position in PowerFiber and PowerComposite technologies. Ongoing work at ITN involves increasing the power capability and cycling current levels on an individual fiber and multi-fiber composite basis, investigating parallel and serial connections when cycling a network of PowerFibers and PowerComposites, and improvements relative to high volume production of PowerFibers and PowerComposites.

Configurations

ITN has fabricated a wide variety of solid-state, thin-film, lithium-based batteries on a variety of fiber materials and diameters.

Traditional and inverted thin-film battery configurations in lithium-ion, lithium-free, and lithium anode cells have been demonstrated. Fiber substrate materials, such as polymer, carbon, metal, and ceramic (SiC, Al_2O_3), have been utilized in PowerFiber ranging from 25μm to 150μm in fiber diameter.

While PowerFibers with nanocrystalline $LiMn_2O_4$, nanocrystalline $Li_2V_2O_5$, and derivative cathodes thereof have been fabricated and tested, the ultimate cathode of choice is crystalline $LiCoO_2$. At elevated power levels, this material provides energy 10 times that of nanocrystalline $Li_2V_2O_5$, and 100 times that of nanocrystalline $LiMn_2O_4$, in the for most applications useful voltage range of 4.2-2.0V.

Performance

ITN's solid-state lithium thin-film batteries have been cycled for more than 90,000 times at 100% depth-of-discharge with an overall capacity loss of 38% (0.0004% capacity loss per cyle). It is therefore our goal to improve the presently demonstrated 2,300 cycles (0.025% capacity loss per cyle) on PowerFibers by more than one order of magnitude in the 2003/2004 timeframe to meet the requirements of many long-term, industrial, civil, and military applications.

To illustrate the projected performance of a crystalline $LiCoO_2$ cathode based PowerComposite we may consider an article with the dimensions of 1.27cm x 2.54cm x 10.16cm (0.5" x 1.0" x 4.0"), yielding a total PowerComposite volume of 32.77cm^3. Utilizing battery integrated 75μm diameter reinforcement fiber with a practical fiber volume fraction (Vf) within the composite of 45%, we can pack 32,850 PowerFibers into such an article.

The active battery area on each PowerFiber is defined by the circumference of the cathode deposited along a portion of the length of the fiber. The presently not optimized $LiCoO_2$ cathode

length within the overall length of this article would be on the order of 7.6cm (3.0") with the routinely deposited thickness of 2µm. This obtains for the projected PowerComposite 6000cm^2 active cathode area with a volume of 1.2cm^3.

ITN has been fabricating thin-film planar and fiber batteries with 2µm thick $LiCoO_2$ cathodes that deliver a capacity density of 0.1mAh/cm^2 at a midpoint voltage of 3.7V, when operated at a current density of 1mA/cm^2. Based on this experimental data we anticipate that the PowerComposite of this illustration will provide at a midpoint voltage of 3.7V, an output current of 6A, a continuous power of more than 22W, a total capacity of 0.6Ah, and a total energy of more than 2.2Wh.

Applications and Opportunities

The primary advantage of integrating power directly onto a single fiber, a flexible fabric or laminate, or a rigid composite structure is the inherent provision of multifunctionality at the fiber or composite level in these materials systems. For examples, power combined with structural reinforcement, power combined with textile weave flexibility, power combined with an optical sensor where the composite matrix is the optically sensitive material. The unique form factor and flexibility of the PowerFiber battery has been highly welcomed by industry and the military.

The multifunctionality lends itself toward the reduction of either structural or power source weight and volume in product applications. Such weight and volume savings are very valuable for aerospace, military, automotive, and other industrial applications. The mechanical structures themselves become the power source, eliminating the mass and storage space required for traditional power sources. Furthermore, PowerFibers and PowerComposites can be distributed and networked without constraint throughout the entire mechanical structure.

A single PowerFiber is a multifunctional product in and of itself. PowerFibers can be utilized in single fiber format, thus integrating power, flexible structure, electrical circuit connection, antenna, RF transceiver, optical sensing (choose optically sensitive fiber material and/or optically sensitive thin-film encapsulation) in and on one single product level.

ITN Energy Systems, Inc., continues to welcome product platform discussions with industrial partners for specific PowerFiber and PowerComposite applications.

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Sources:

Dr. Bernd J. Neudecker
ITN Energy Systems, Inc.
8130 Shaffer Parkway
Littleton, Colorado 80127-4107
USA
303-285-5119
303-285-0581 fax
bneudecker@itnes.com

Mr. Martin H. Benson
ITN Energy Systems, Inc.
8130 Shaffer Parkway
Littleton, Colorado 80127-4107
USA
303-285-5152
303-285-0812 fax
mbenson@itnes.com

Photo caption:

Figure 1: *(a) SEM micrograph of a 33μm carbon substrate PowerFiber; (b) An inverted lithium-free PowerFiber deposition illustration, for example, a fiber, a first layer anode current collector, a second layer electrolyte, a third layer cathode, a fourth layer cathode current collector, a fifth layer encapsulant; (c) an exemplary PowerFiber reinforced rigid composite; (d) an exemplary PowerFiber reinforced flexible composite.*